# Combined Multiple Attenuation Methods and Geological Interpretation : Seram Sea Case Study 2D Marine Seismic Data

# *Kombinasi Metode Atenuasi Multiple dan Interpretasi Geologi : Studi Kasus Data Seismik Laut 2D Laut Seram*

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**ABSTRACT:** Multiple often and always appear in marine seismic data due to very high acoustic impedance contrasts. These events have undergone more than one reflection. This causes the signal to arrive back at the receiver at an erroneous time, which, in turn, causes false results and can result in data misinterpretation. Several types of multiple suppression have been studied in literature. Methods that attenuate multiples can be classified into three broad categories: deconvolution methods; filtering methods and wavefield prediction subtraction methods. The study area is situated on Seram Sea in between 131°15'E – 132°45'E and 3°0'S – 4°0'S, Seram Trough which is located beneath Seram Sea at northern part of the Banda-Arc – Australian collision zone and currently the site of contraction between Bird's Head and Seram. This research uses predictive deconvolution and F-K filter to attenuate short period multiple from their move out, then continued by Surface Related Multiple Elimination (SRME) method to predict multiple that cannot be attenuated from previous method, then followed by Radon transform to attenuate multiple that still left and cannot be attenuated by SRME method. The result of each method then compared to each other to see how well multiple attenuated. Predictive deconvolution and F-K filter could not give satisfactory result especially complex area where multiple in dipping event is not periodic, SRME method successfully attenuate multiple especially in near offset multiple without need subsurface information, while SRME method fails to attenuate long offset multiple, combination of SRME method and Radon transform can give satisfactory result with careful selection of the Radon transform parameters because it can obscure some primary reflectors. Based on geological interpretation, Seram Trough is built by dominant structural style of deposited fold and thrust belt. The deposited fold and thrust belt has a complexly fault geometry from western zone until eastern of seismic line.

**Keywords :** F-K Filter, Surface Related Multiple Elimination (SRME), Radon Transform, Seram Trough

***ABSTRAK:*** Pengulangan ganda sering dan selalu muncul dalam data seismik laut karena kontras impedansi akustik yang sangat tinggi. Peristiwa ini telah mengalami lebih dari satu refleksi, Hal ini menyebabkan sinyal untuk kembali ke penerima pada waktu yang salah, yang pada gilirannya menyebabkan hasil yang salah dan dapat menyebabkan salah tafsir. Beberapa jenis pengulangan berganda telah dipelajari dalam literatur. Metode yang atenuasi pengulangan ganda dapat diklasifikasikan ke dalam tiga kategori besar: metode dekonvolusi; metode penyaringan dan metode substraksi prediksi medan gelombang. Wilayah studi terletak di Laut Seram di antara 131°15'E - 132°45'E dan 3°0'S - 4°0'S, Palung Seram yang terletak di bawah Laut Seram di bagian utara Busur Banda dan zona tabrakan Australia dan saat ini situs kontraksi antara "Kepala Burung" Papua dan Seram. Penelitian ini menggunakan dekonvolusi prediktif dan filter F-K untuk atenuasi pengulangan periode pendek dari perpindahannya, kemudian dilanjutkan dengan metode *Surface Related Multiple Elimination* (SRME) untuk memprediksi multiple yang tidak dapat dilemahkan dari metode sebelumnya kemudian melanjutkan transformasi Radon untuk atenuasi pengulangan ganda yang masih tersisa dan tidak dapat dilemahkan oleh metode SRME, hasil dari masing-masing metode kemudian dibandingkan satu sama lain untuk melihat seberapa baik beberapa pelemahan. Dekonvolusi prediktif dan filter FK tidak dapat memberikan hasil yang memuaskan terutama area kompleks di mana pengulangan ganda dalam bidang miring cenderung tidak periodik, metode SRME berhasil melemahkan kelipatan ganda pada jarak dekat tanpa memerlukan informasi di bawah permukaan, sedangkan metode SRME gagal melemahkan pengulangan ganda pada jarak panjang, kombinasi metode SRME dan transformasi Radon dapat memberikan hasil yang memuaskan dengan pemilihan parameter transformasi Radon yang cermat karena dapat mengaburkan beberapa reflektor utama. Berdasarkan interpretasi geologi, Palung Seram dibentuk oleh struktur dominan dari endapan jalur lipatan dan sesar. Endapan jalur lipatan dan sesar tersebut memiliki geometri sesar yang kompleks dari arah bagian barat sampai ke bagian timur.

***Kata kunci :*** *filter F-K, Surface Related Multiple Elimination (SRME), transformasi Radon, Palung Seram*

## INTRODUCTION

Multiple often and always appear in marine seismic data due to very high acoustic impedance contrasts. These events have undergone more than one reflection. They are produced in the data gathering process when the signal doesn't take a direct path from the source to the geologic event and finally back to the receiver on the surface. This causes the signal to arrive back at the receiver at an erroneous time, which, in turn, causes false results and can result in data misinterpretation.

There are several type of multiples water-bottom multiples of first- and second-order, free-surface multiples of first- and second-order, peg-leg multiples of first- and second-order, intrabed multiples of first- and second-order, and interbed multiples of first- and second-order (Yilmaz, 2001). Imaging in deep water environments poses a specific set of challenges, both in the data pre-conditioning and imaging among which is "hard" water bottom, which results in high amplitude multiple reflections relative to primary energy (Stewart, 2007).

Several types of multiple suppression have been studied in literature. Methods that attenuate multiples can be classified into three broad categories: (1) deconvolution methods that use the periodicity of multiples; (2) filtering methods that exploit the difference between the normal moveout for primary events and that for multiples; and (3) wavefield prediction and subtraction methods that are based on the predictions from modelling or inversion of the recorded seismic wavefield (Pan, 2015).

Surface Related Multiple prediction by feedback iterative method based on wave equation does not depend on any assumptions about underground media nor does it need any prior geological structure information, or source characteristics (Li *et al.*, 2014) but in order to success it requires dense and regular acquisition geometry. SRME technique has become popular in deep water. Near offset multiples in particular, are better attenuated than those with Parabolic Radon (Stewart, 2007). Parabolic Radon multiple removal which relies on residual move-out of the multiple relative to a primary. This approach may work well for long-period multiples but often fails for short-period ones. Furthermore, it is difficult to attenuate multiples effectively well at near offsets (Min *et al.*, 2016).

The major complex geological structure is Seram Trough which is located beneath Seram Sea at northern part of the Banda-Arc – Australian collision zone and currently the site of contraction between Bird's Head and Seram (Pairault *et al.*, 2003). There are no perfect methods to attenuate multiple because of that this research is aimed to combine SRME and Radon Transform to get better image of subsurface without interfere with multiple that make data misinterpretation especially in complex area like Seram Sea.

## DATA AND METHODS

The study area is situated on Seram Sea in between 131 15'E – 132 45'E and 3 0'S – 4 0'S (Figure 2). 2D seismic surveys shot along the Seram Trough were done by Marine Geological Institute. Line 18 from that survey is processed by seismic processing software to get better understand multiple respond and attenuation method in deep water seismic data. Seismic data were acquired using Sercel Inc. 60 channels single-streamer and 850 cu. in. power pressure airgun at average 4 knot vessel speed (Table 1).

This research uses predictive deconvolution and F-K filter to attenuate short period multiple and simple multiple from their move out, then continued by SRME to predict multiple that cannot be attenuated from previous method then followed by Radon transform to attenuate multiple that still left and cannot be attenuated by SRME. The result of each method is compared each other to see how well multiple attenuate (Figure 1).

Frequency-wavenumber filtering or better known as *F-K* filter is a process of noise attenuation in the *F-K* domain. This method was applied by transforming the seismic data in the t-x domain into the *F-K* domain using the Fourier transform. As the seismic data were transformed in the *F-K* domain, the linear event will remain the same in both domains, however the signal and noise can now be separated based on the dipping angle (Zhou, 2014). This way we can properly separate this two different signal and later mute the unwanted seismic noise. Although it was more computational extensive compare to the frequency filtering, this method allows the elimination of the coherent noise without reducing the frequency content of the seismic data.

Predictive deconvolution is based on the autocorrelation function of the time series that can be used to remove the periodicity, and hence, the multiples

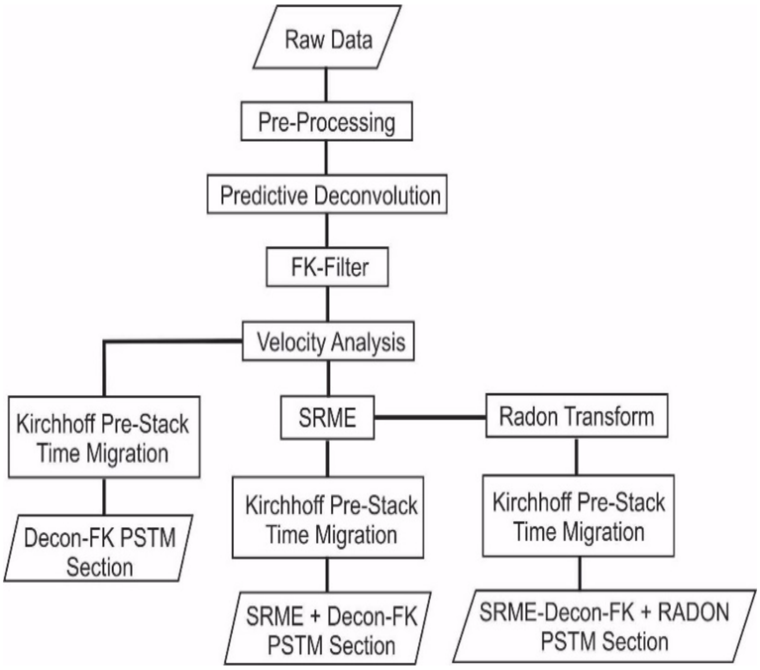


Figure 1. Flowchart of Combined Multiple Attenuation Method


Figure 2. Line 18 Seismic Acquisition

Table 1. Line Acquisition Parameters

| | |
|---|---|
| Configuration | Off-end |
| Channel Number | 1 - 60 Channel |
| Azimut | 56° |
| Shot Interval | 25 m |
| Group Interval | 12.5 m |
| Shot Number | 5089 |
| Minimum Offset | 150 m |
| Maximum Offset | 887,5 m |
| Fold | 15 |
| Line Length | 131,14 Km |
| Sampling Rate | 2 ms |

(Henley and Wong, 2013). Thus, it is useful in suppressing short period free-surface multiples generated at shallow reflectors (Peacock and Treitel, 1969). The predictive deconvolution methods are effective in suppressing short-period, free-surface multiples generated at shallow reflectors but are generally less effective in deep water environments where the period of the multiples is longer relative to the length of the record (Cao *et al.*, 2003).

Radon transform algorithm is typically employed to transform seismic data from the offset-time (x-t) domain to the time-moveout ( -p) domain. Radon transform was first introduced by Radon (Radon, 1917). The linear approach maps linear events in the input seismic data into a point in the  -p domain (Singh *et al.*, 2008), where they can be separated by muting before inverse transform back to the x-t domain. In this way, the approach is capable of attenuating ground rolls and other linear noise events from the input gather (Ogagarue and Ebeniro, 2014).

Surface Related Multiple Elimination (SRME) is, at least in principle, able to predict and attenuate all free-surface-related multiples. This method is data driven and does not rely on any simplifying assumptions regarding the subsurface (Hokstad, 2006). SRME method can predict all surface-related multiples, provided all the necessary sub-events recorded within the aperture and azimuth of the acquisition line. The surface is assumed to be perfectly reflecting boundary and the input data are assumed to have been regularized prior to the application of 2D SRME (Nainggolan and Setiady, 2017). SRME is fully data driven, which means no auxiliary prior information needs to be supplied, such as, velocity and horizon. SRME does not require any subsurface information, nor does it make any assumptions about seismic events such as hyperbolicity or moveout separation between primaries and multiples (Naidu *et al.*, 2013).

## RESULTS

### Combined Multiple Attenuation

There are four zones based on acquisition sequences along seismic Line 18, each of them tested using the same parameters to see how multiple attenuates in different geological setting.

### Zone 1

Seismic data has been through some pre-processing using standard conventional procedure such as muting, killing, band pass filtering to enhance S/N ratio. Predictive deconvolution is first applied to the data to attenuate simple short period multiple along with F-K filter to attenuate large move out multiple from the primary. Figure 4a shows that surface-related multiple still exists, then SRME method applied (Figure 4b) to F-K filter output but there is no improvement

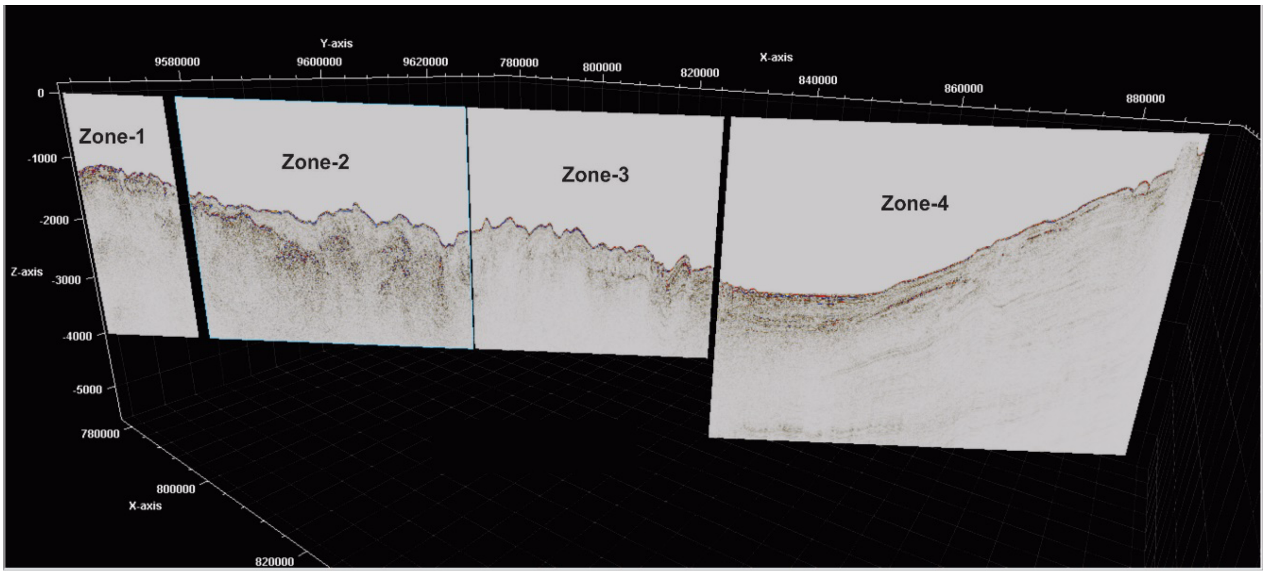


Figure 3. Number of zones in Line 18

appears. It seems SRME fails to predict the multiple due to inaccurate model prediction. Stewart *et al.* (2007) mentioned it has become clear after extensive testing that "direct" multiples are best attenuated using SRME technique (Verschuur *et al.*, 1992). However, correct parameterization is critical for success.

In Figure 4c, after radon filter water bottom multiple has successfully eliminate surface relate multiple that fails to attenuate by SRME due to inaccurate parameters. Successful results of combined multiple attenuation methods are clearly shown on CDPs 200, 500 and 1400.

**Zone 2**

Zone 2 has no clear reflector events so it hard to see the multiple event and how it's attenuated (Figure 5) however it has strong short period multiple that failed to eliminated by simple predictive deconvolution and still exist after SRME, Radon Transform then applied to the data in order to improve the image quality (Figure 5c), it shows Radon filter can eliminate short period multiple, but in dipping reflector that seems clear in SMRE turns to be unclear after Radon filter (red arrow in Figure 5).

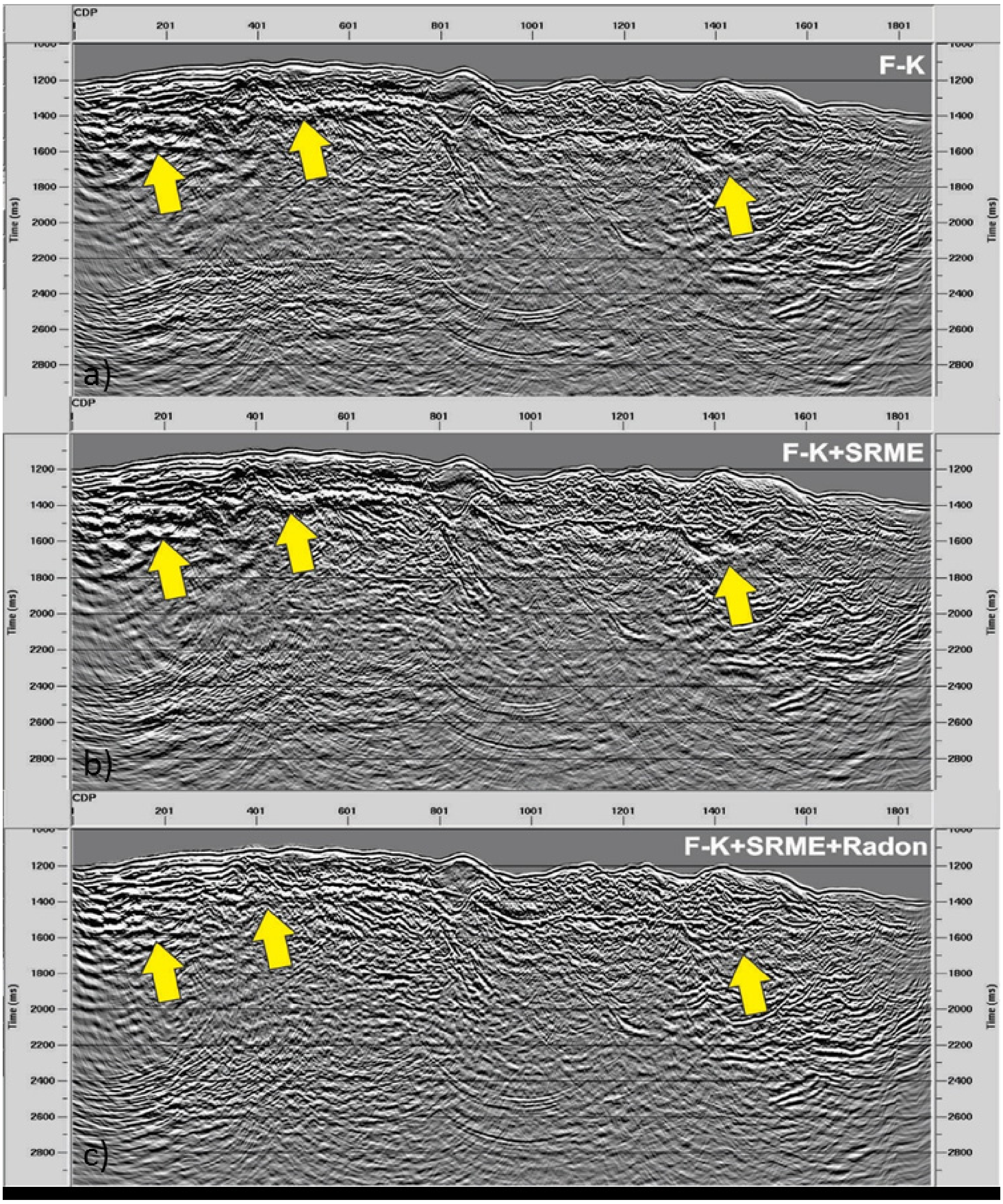


Figure 4. Result of zone 1 (Changes of reflections are marked by yellow arrows)

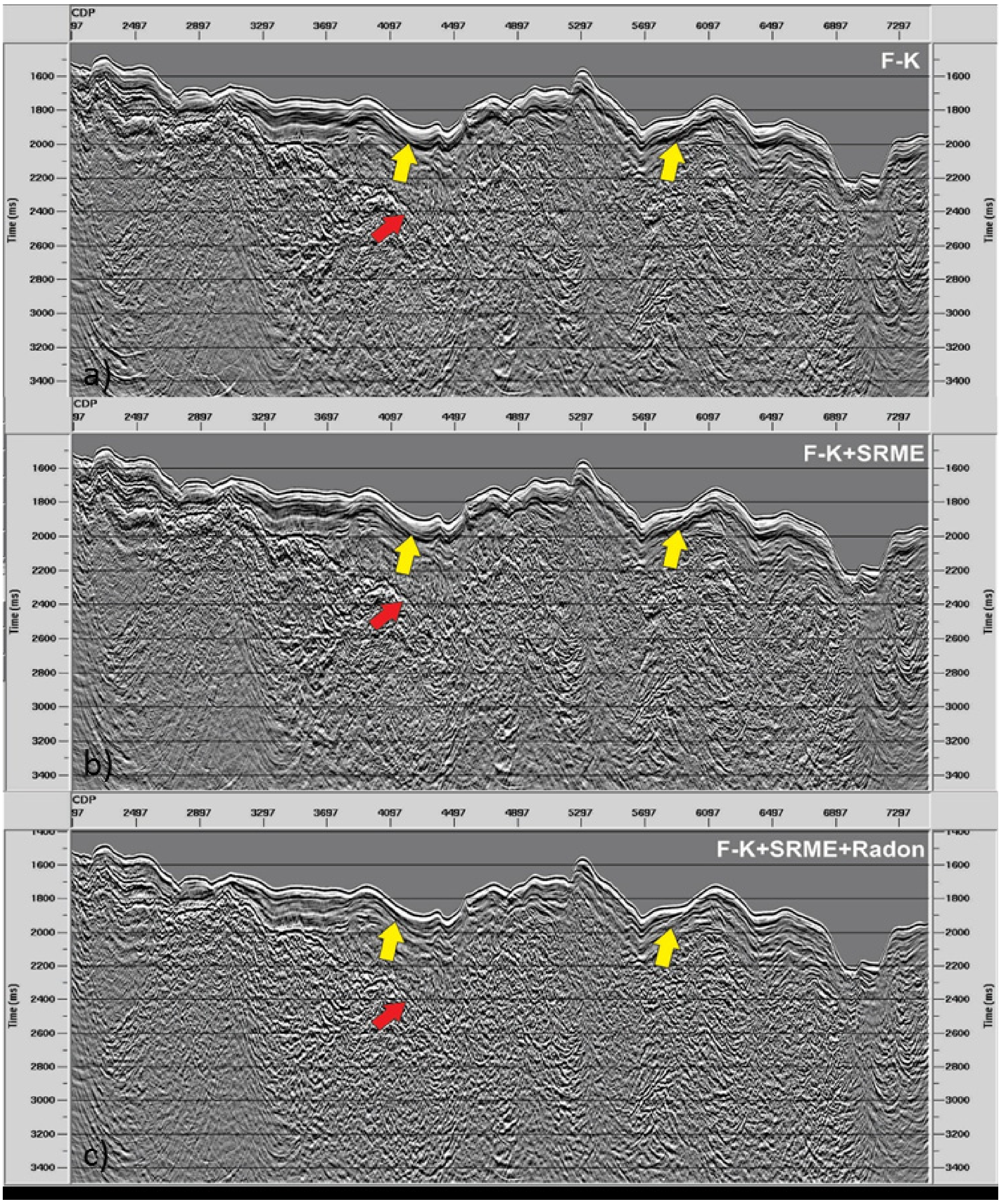


Figure 5. Result of Zone 2 (Changes of reflections are marked by yellow and red arrows)

**Zone 3**

Zone 3 appears with no many reflection events and still comes with strong surface related multiple after the primaries (Figure 6), SRME result has no improvement from predictive deconvolution and F-K filtering, Radon filter gives quite good result compared to SRME however it has some issues, water bottom multiple that does not appear in SRME now clearly can be seen in Figure 6c.

**Zone 4**

Zone 4 (Figure 7) have strong water bottom multiple, that can be clearly seen in CDP 12000 – 15000 (depth interval 5500 – 6500 ms), simple predictive deconvolution and F-K Filter cannot attenuate this multiple, SRME give satisfactory result to attenuate this multiple while preserve primaries especially in near offset data.

In Figure 8, differences between SRME and radon filter seem more clear while SRME attenuate water bottom multiple and preserve primaries amplitude, radon filter is much powerful in internal multiple

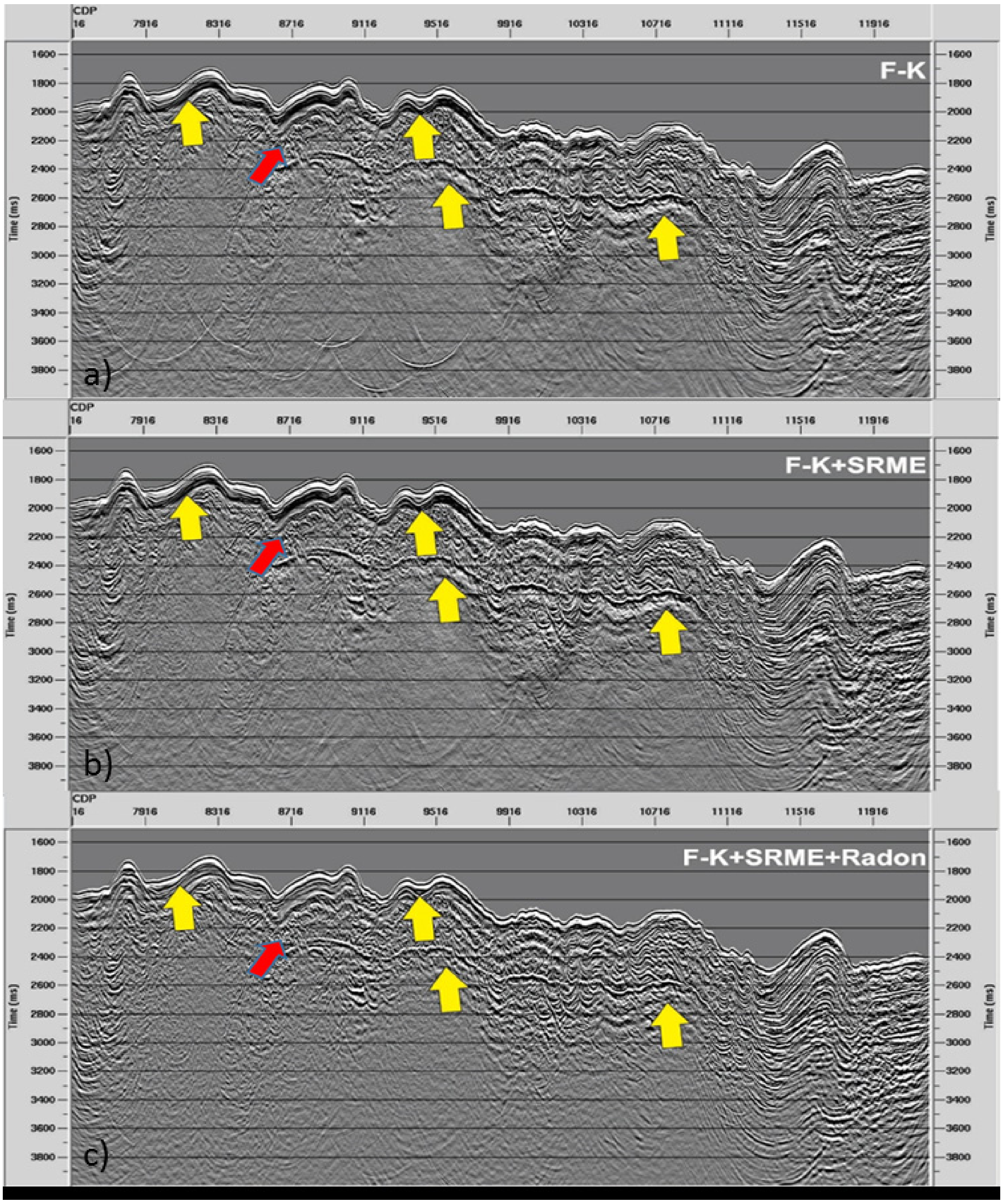


Figure 6. Result of zone 3 (Changes of reflections are marked by yellow and red arrows)

attenuation that cannot be predicted by SRME model however some primary reflectors severely attenuate after Radon filter in Figure 8c.

**Interpretation**

Interpretation is done by looking at continuity patterns in the reflector field then interpret the geological structures that are imagined. Line 18 is divided into 4 zones of pre stack time migration results. Seram Sea region is part of the Banda Arc which consists of an inner volcanic arc and an outer non-volcanic arc of island formed principally of sedimentary, metamorphic and some igneous rocks of Permian to Quaternary age (Pairault *et al.*, 2003). From Line 18, it can be seen that the eastern zone, especially in the Seram Trough, is dominated by sedimentation deposits while the western area is dominated by less imaged zones due to the intensive faulting area. Generally, there is no basin floor, with the Western slope of the Bird's Head being overridden by the Seram fold and thrust belt (FTB) (Teas, 2009), therefore in the Western zones 1, 2 and 3 it is only dominated by fault structures.

Zone 1 of Line 18 (Figure 9) is only imaged at the main reflector at 1500 ms, where reflectors above 1500

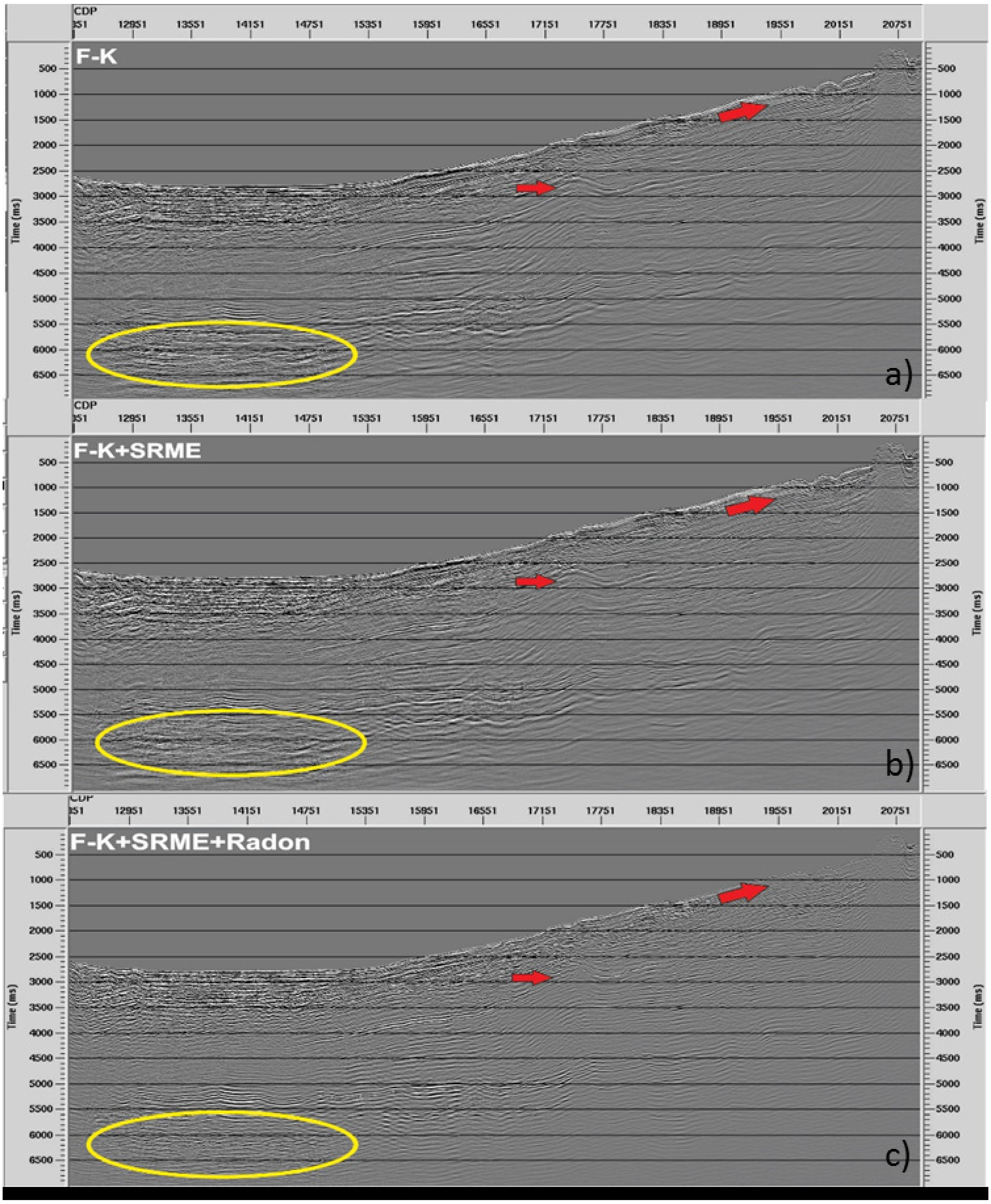


Figure 7. Result of zone 4 (Short and surface related multiples are marked by red arrows and yellow circles)

ms are no longer imaged probably due to the turbiditic bedrock.

In zone 2 (Figure 10) the results are still dominated by bedrock characterized by the lack of a reflector, there are several faults created by compression so that the faults are dominated by reverse faults due to FTB in West part of Seram Sea. The reflector at CDP 2000 - 4500 shows a downward pattern towards the bedrock which can be caused by strong compression in both directions.

The geological structure image in zone 3 (Figure 11) is dominated by reverse faults with some minor faults at the range of 2500 - 2800 ms, the reverse fault can be affected by the compression force from the northeast direction, the imagined reflector is affected by both ends of reverse faults. The lower part is dominated by bedrock in the range 3000 - 4000 ms. There are also anticline and cycline structures at CDP 11000-12000.

The results of the interpretation of segment four are dominated by the deposited sediments on the base of

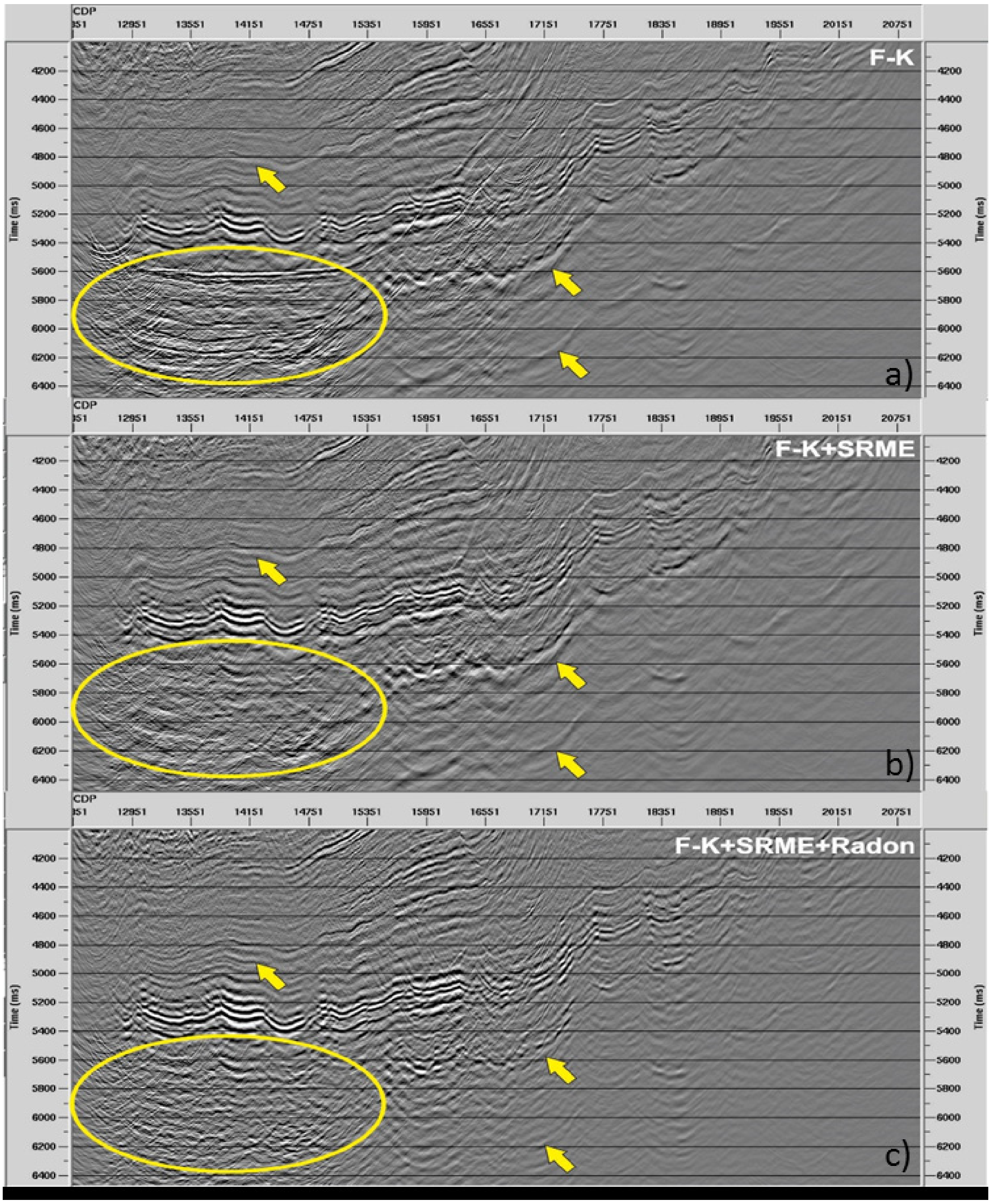


Figure 8. Result of zone 4 within depth range 4300- 6500 ms (Combined multiple attenuation are marked by yellow arrows and circles)

the Seram Trough (Figure 12), some depositional sequences are obtained based on the continuity pattern of the reflector and the recorded amplitude. As the upper sequences cannot be matched to stratigraphic units previously identified they are named from their appearance on the seismic lines: a transgressive sequence (TS) and two progradational sequences (PS1 and PS2) (Pairault *et al.*, 2003). The Transgression sequence is above a wavy pattern at the depositional tip which can indicate an unconformity (Patria, 2017), a sequence whose location below this unconformity is the early New Guinea limestone (Pairault *et al.*, 2003). The transgressive sequence is characterized by a weak amplitude above the strong amplitude of the unconformity boundary, PS1 is then deposited over the TS sequence, PS1 covers almost all areas that are thought to be of early Pleistocene age and PS2 is deposited above PS1 with early Pleistocene age (Patria, 2017). The sedimentation process of PS1 continues until now and is a stratum that continues to grow. In zone 4, there are also several faults, including faults due to gravity from the sedimentation process, especially on PS2.

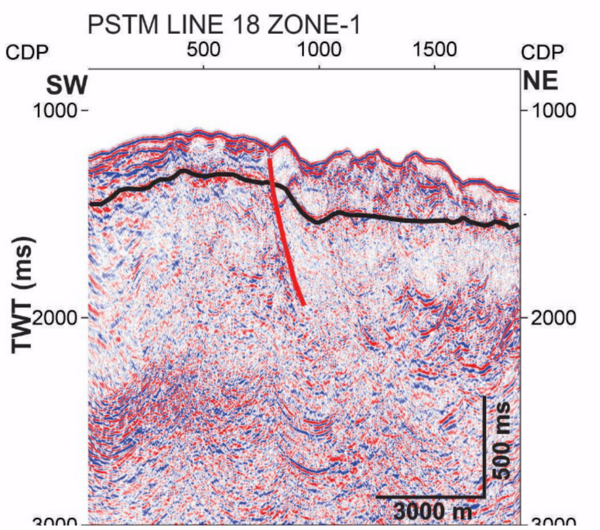


Figure 9. Interpretation of line 18 zone 1

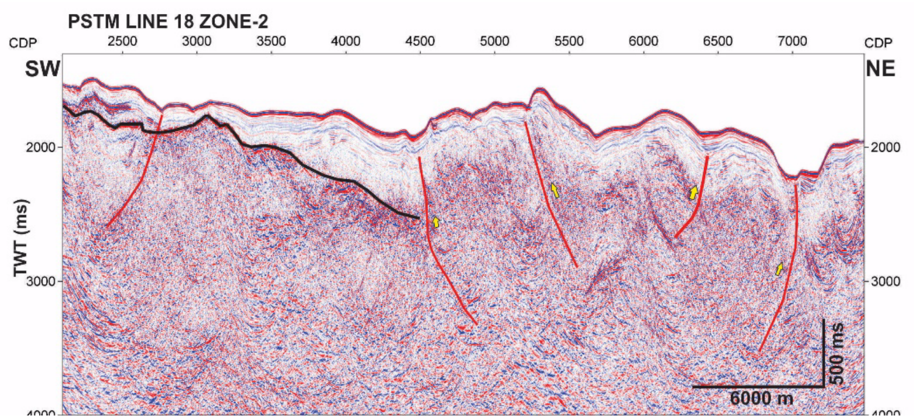


Figure 10. Interpretation of line 18 zone 2

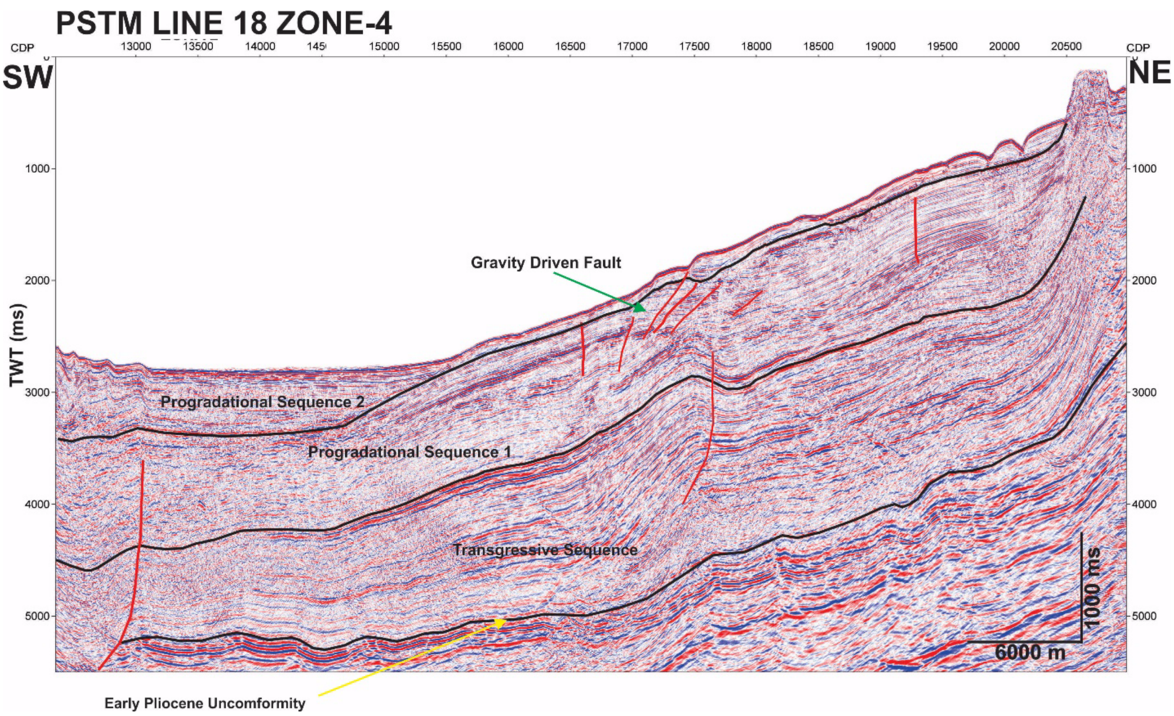


Figure 11. Interpretation of line 18 zone 3

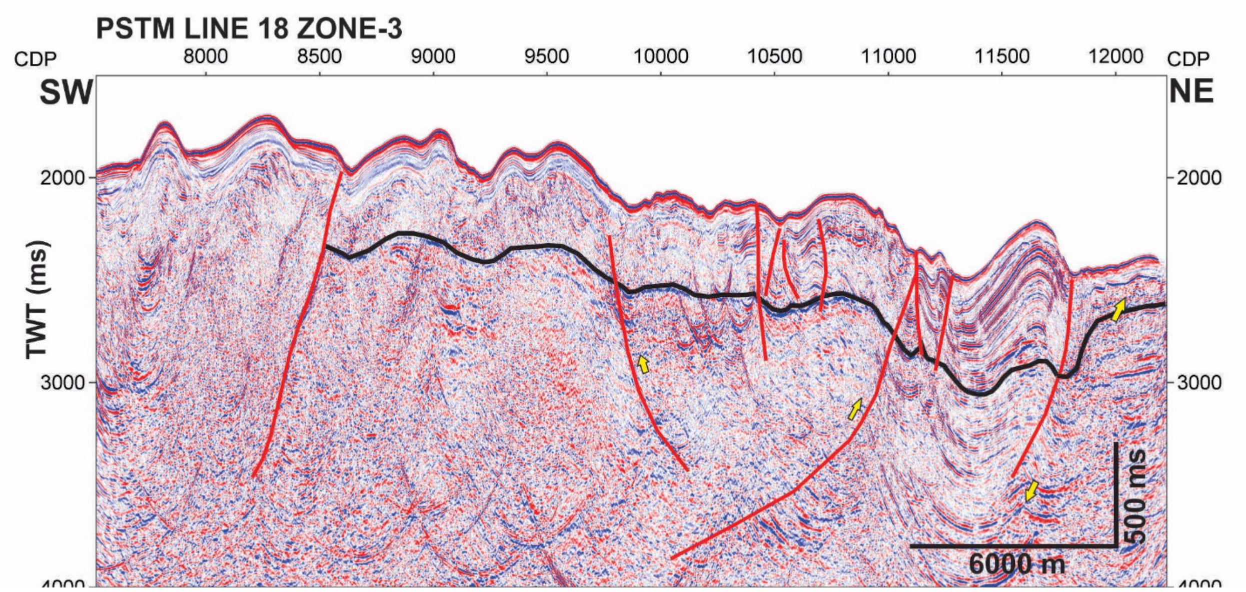


Figure 12. Interpretation of line 18 zone 4

**DISCUSSIONS**

Predictive deconvolution and F-K filter do not give satisfactory result in multiple attenuation in this seismic line because rough seabed with dipping event and inaccurate predictive deconvolution parameter. SRME give the best result for near offset long period multiple in zone 4 at depth interval 5600 – 6400 ms, while it is still preserve primary reflector amplitude. SRME method predictive multiple based on data driven so there is no need subsurface information to predict the multiple, it works better in near offset however if the measured data is non-ideal in some sense, it means that multiples cannot be properly estimated and multiple suppression is limited and that artefacts may be introduced (Verschuur, 2006). Radon transform, that is applied after SRME, shows satisfactory result especially in internal multiple that still remain after SRME, Radon Transform works by transform the data from t-x domain into -p domain then separate multiple by its differential moveout velocity therefore it works better in long offset where the velocity moveout is larger between primaries and multiple however in near offset data velocity moveout barely distinguishable because primaries and multiple almost have the same arrival time, Radon Transform may obscure some primary reflectors due to not large enough moveout differences and need to do some quality control after invers the data from -p domain.

Zone 3 and 4 has been studied by Teas *et al.* (2009) said that western domain characterized at the seafloor by large blocks of coherent seafloor separated by zones of complicated morphology. These features are thought to represent the character at depth of independent thick blocks bounded by fault systems. The basal detachment fault in the west is much deeper cutting down into the older under thrust section.

**CONCLUSION**

Predictive deconvolution and F-K filter could not give satisfactory result especially complex area where multiple in dipping event is not periodic, if deconvolution parameter determine accurately it can attenuate short period multiple satisfactorily, SRME successfully attenuate multiple especially in near offset multiple without need subsurface information it predict multiple by predictive model from the data itself so in order to success the primary data have to be ideal while SRME failed to attenuate long offset multiple, combination of SRME and Radon transform can give satisfactory result because radon transform may work well for long-period multiples but often fails for short-period ones with careful selection of the Radon transform parameters because it can obscure some primary reflectors.

Seram Trough is built by dominant structural style of deposited fold and thrust belt. The deposited fold and thrust belt has a complexly fault geometry from Western zone until Eastern of seismic line. The Western zone of fold and belt is characterized as a deeper fault rigid block to depositional of transgressive sequences in the Eastern.

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